A note on jet quenching in central Cu+Cu collisions

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(Dated: July 26, 2005)

We present analytic predictions on the system size dependence of jet quenching and the p_T dependence of the nuclear suppression in central $Cu + Cu$ collisions.

PACS numbers: 12.38.Bx,12.38.Mh,25.75.-q

An approximate analytic formula for the energy loss calculated in the Gyulassy-Levai-Vitev approach relates $\langle \Delta E \rangle$ to the size and the soft parton rapidity density of the medium. For the case of (1+1)D Bjorken expansion we find in the limit of infinite kinematic bounds

$$\frac{\langle \Delta E \rangle}{E} \approx \frac{9 C_R \pi \alpha_s^3}{4} \frac{1}{A_\perp} \frac{dN^g}{dy} L \, \frac{1}{E} \ln \frac{2E}{\mu^2 L} + \cdots \, . \tag{1}$$

In Eq. 3 L is the transverse size of the medium and $A_\perp$ is the transvesre area. $C_R = 4/3$ (9) for quarks (gluons), respectively is the second Casimir in the fundamental (adjoint) representations. Its physical meaning is the average sqaured color chargr of the parent parton. Numerical simulations of $\langle \Delta E \rangle / E$ clearly indicate a weaker dependence of the fractional energy loss on the jet energy.

The key to understanding the dependence of jet quenching on the nuclear species is the A or N_{part} dependence of the characteristic plasma parameters in Eq. (3). We recall that

$$\begin{aligned} \frac{dN^g}{dy} \propto \frac{dN^h}{dy} \propto A \propto N_{part} \, , \\ L \propto A^{1/3} \propto N_{part}^{1/3} \, , \\ A_\perp \propto A^{2/3} \propto N_{part}^{2/3} \, . \end{aligned} \tag{2}$$

Therefore, the fractional energy loss scales as

$$\frac{\langle \Delta E \rangle}{E} \propto A^{2/3} \propto N_{part}^{2/3} \, . \tag{3}$$

The prediscted scaling of the energy loss can be studied through the nuclear species dependence of the suppression ratio. We construct an intuitive modlel of nuclear supression based on an underlying parton spectrum

$$\frac{d\sigma^{parton}}{dy d^2 p_T} \propto \frac{1}{p_T^n} \tag{4}$$

If a fraction of the energy (or eqyivalently p_T) is lost, the initial parton energy should be larger and

$$\frac{1}{N_{col}} \frac{d\sigma^{parton}}{dy d^2 p_T} \propto \frac{1}{p_T^n (1 + \langle \Delta p_T \rangle_{eff} / p_T)^n} \tag{5}$$

The nuclear modification for observable hadrons then reads

$$R_{AA} = \frac{1}{(1 + \kappa' N_{part}^{2/3})^{n-2}} \, . \tag{6}$$

where the factor $n-2$ is associated with the phase space.

To clarify the A and N_{part} dependence of jet quenching it is useful to identify the variables where such dependence is linear. It is thus convenient to plot

$$\ln R_{AA} = -\kappa N_{part}^{2/3} \, , \tag{7}$$

if $\kappa' N_{part}^{2/3}$ is not large. Here $\kappa = (n-2)\kappa'$. The main analytic prediction for the nuclear modification as a function of the system size at fixed center of mass energy (which ensures fixed n), which follows form the GLV approach, is given in Figure 1. It is tied to the magnitude of the suppression established in central Au+Au collision and consistent with the full numerical simulation at this energy and this system. The uncertainty in the established quenching is reflected in the uncertainty band versus the nuclear species. The traditional way of analyzing R_{AA} is also shown in the insert but has a disadvantage of obscuring the functional form of high p_T single inclusive hadron attenuation. It is clear that a light nuclear system, such as $O + O$ is needed to further constrain the onset of attenuation effects in the QGP.

We have focused on the most central nuclear collisions and used impact parameters $b = 1 \; fm$ for the lightest nuclear species and $b = 3 \; fm$ for the heaviest nuclei. For $Cu + Cu$ collisions we used $b = 2 \; fm$. On an optical Glauber model calculation we evaluated $N_{part}^{2/3}$ (rounded to the nearest integer) using $\sigma_{pp}^{in} = 42 \; mb$ and a Wood-Saxon nuclear density. Results are given in Table I.

With the simple analytical model in place we now proceed to the numerical simulation of the quaneching of high p_T inclusive pions in central $Cu + Cu$ collisions at $\sqrt{s_{NN}} = 200 \; : \; GeV.$. This part is in the works and expected to be finished in the next few days. It clearly requires more work than the analytic model above. The questions we want to answer are

- In the $5 \; GeV \; < p_T < 10 \; GeV$ do our numerical results roughly follow the analytical prediction given above. A Band will be computed similarly to the $Au + Au$ case.
- What is the p_T dependence of the suppression in the $5 \; GeV \; < p_T < 10 \; GeV$ range? Is it *approximately* flat as it was predicted in $Au + Au$?

We calculated numerically the ratio of the fractional energy loss for $Au + Au$ collisions and $Cu + Cu$ collisons

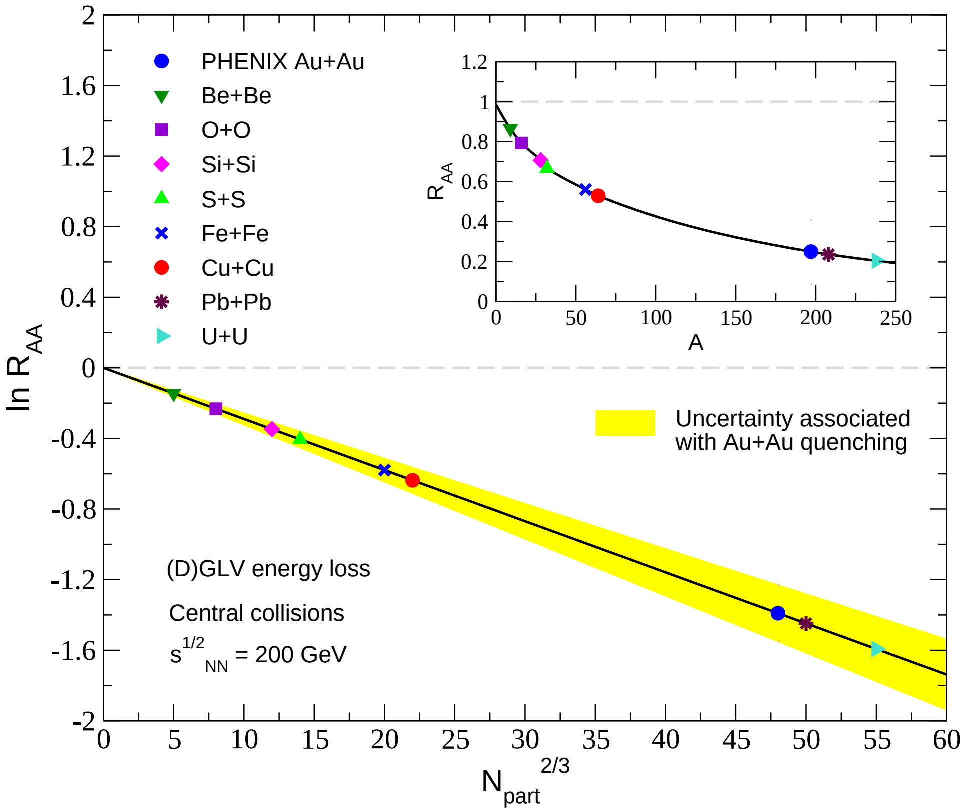

FIG. 1: The predicted linear dependence of jet quenching in natural variables $\ln R_{AA}$ versus $N_{part}^{2/3}$ for central collisions of ^{9}Be, ^{16}O, ^{28}Si, ^{32}S, ^{56}Fe, ^{64}Cu, ^{208}Pb and ^{238}U. The central $Au + Au$ collisions quenching and its uncertainty fixes the slope and error band of the predicted dependence. The insert shows the behavior of the nuclear modification versus the system size A.

TABLE I: Summary of the relevant parameters for the particle species shown in the Figure 1. $N_{part}^{2/3}$ is rounded to the nearest integer.

Species	^{9}Be	^{16}O	^{28}Si	^{32}S	^{56}Fe	^{64}Cu	^{197}Au	^{208}Pb	^{238}U
b $[fm]$	1	1	1.5	1.5	2	2	3	3	3
$N_{part}^{2/3}$	5	8	12	14	20	22	48	50	55

calculated to first order in opacity. While the analytic predictions is close to $(\langle \Delta E\rangle/E)_{AuAu}/(\langle \Delta E\rangle/E)_{CuCu} \simeq$ 2.1, numerically we find that the ratio is closer to 1.9 or 10% smaller. This nonlinearity can be attributed to the cancelation of a smaller part of the collinear phase space due to the density (temperature) dependence of μ. For $\langle N^g\rangle$ this ratio is close to 1.8 due to the larger sensitivity to the small ω/E fraction of the spectrum. In the ful simulation we use this factor to scale the radiative spectra carefully calculated to 3rd order in opacity.

The answers:

Thanks for your interest. I will keep you updated on the new results.

This work is supported by the J. R. Oppenheimer Fellowship of the Los Alamos National Laboratory and by the US Department of Energy.

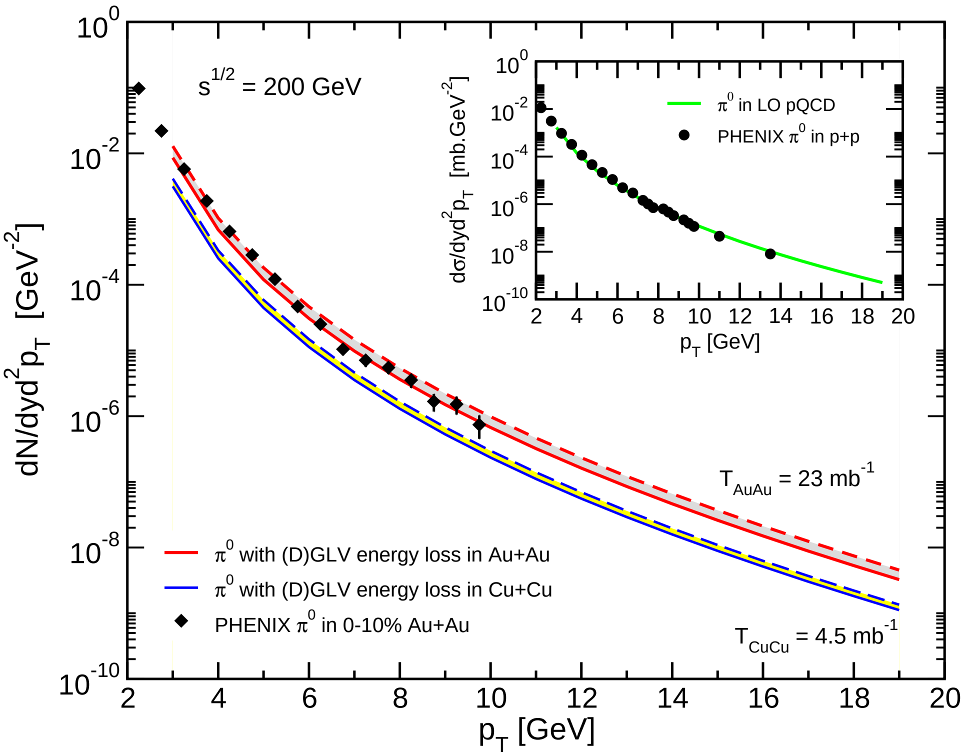

FIG. 2: The predicted invariant multiplicity distribution of neutral pions in central $Au + Au$ collisions at $\sqrt{s_{NN}} = 200\ GeV$ for medium density $dN^g/dy = 800 - 1150$ and $T_{AuAu} = 23\ mb^{-1}$. The same calculation for $Cu + Cu$ collisions for medium density $dN^g/dy = 250 - 370$ and $T_{CuCu} = 4.5\ mb^{-1}$. The insert shows the cross section for π^0 production in $p + p$ collisions to LO pQCD compared to the PHENIX data.

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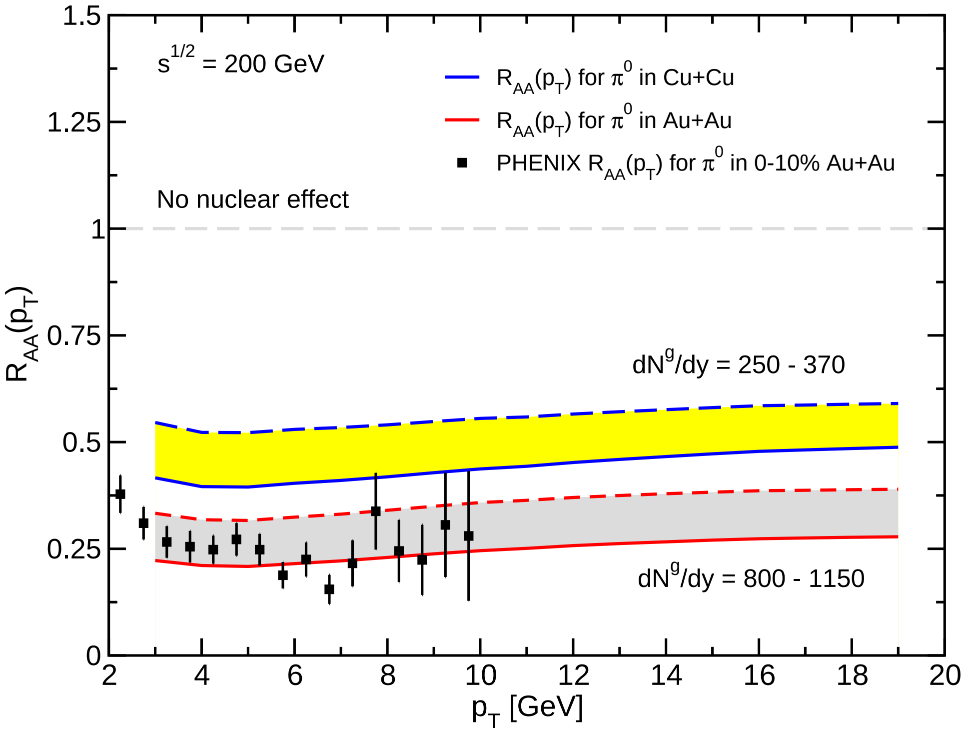

FIG. 3: The nuclear modification factor R_{AA} versus p_T for the same medium sizes and densities as in the previous figure. Note that the prediction for $Cu + Cu$ is for a symilarly flat suppression ratio as in $Au + Au$ at high p_T.